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OBSERVING OCEAN WAVES

U. S. NAVY WEATHER RESEARCH FACILITY
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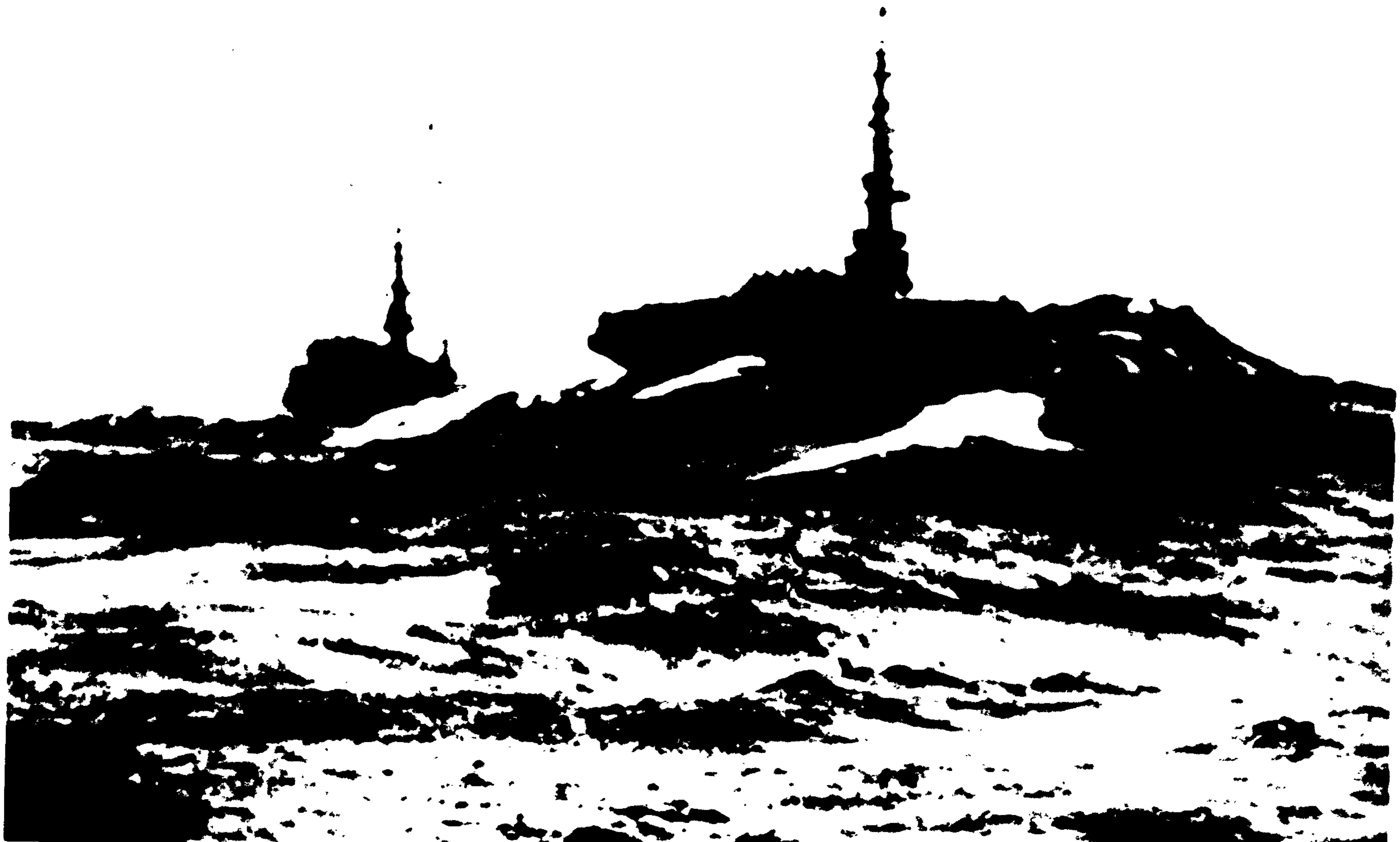

FRONTISPIECE

FOREWORD

This report was prepared under Task 40, ' The Influence of Weather on Naval Operations."

After undertaking research to determine the influence of weather on replenishment and carrier operations, it became apparent that deficiencies in the data concerning ocean wave characteristics exist. Before any substantial progress in the study of replenishment and carrier operations can be made, improved and standardized ocean wave observations must be available.

This text is written primarily for quartermasters who are generally responsible for the observing and reporting of ocean waves aboard U. S. Navy ships. It presents, in a concise form, the characteristics of ocean waves and explicitly points out the differences between wind waves and swell. Standard methods for observing wave direction, period, and height are then presented. Hopefully, this publication will serve as a common ground for the quartermasters in the observing of ocean waves.

The publication was written by Mr. James C. McLean, Jr., Assistant Task Leader, and edited by Mr. John M. Mercer and Mr. Rene'V. Cormier.

This report has been reviewed and approved on 9 October 1964.

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INTRODUCTION

One of the shipboard duties of the quartermaster, when an aerographer is not on board, is the observation and reporting of the weather and the state of the sea. These reports are used, in one form or another, by more people than any other transmission being broadcast from the ship; they go to the Navy Weather Centrals, the U. S. Weather Bureau, and the weather services of many foreign countries.

It is from the many individual reports from ships and land stations that the present weather picture and the weather forecasts are prepared at the various weather stations throughout the world. Reports from ocean areas are especially important because there are fewer reports from ocean areas than from land areas, and the weather forecaster often has no way to verify the accuracy of the ocean report because there are no nearby stations with which to check for comparison. For these reasons it is important that each ship's weather report gives the best possible picture of the weather and the state of the sea at the time the observation was made. The forecaster must be able to rely on the information he receives.

This text is designed to provide information which will help in accomplishing one segment of the weather report, that of reporting the state of the sea; present information available to the quartermaster or aerographer on this subject is inadequate. This publication explains what waves are, how they are developed by the wind, and describes methods of measuring their various characteristics. It is hoped that a better understanding of sea conditions will lead to more accurate state-of-the-sea reports, which in turn should lead to better forecasts to the fleet.

1. THE DESCRIPTION OF OCEAN WAVES

1.1 Wind Waves

Any disturbance of the smooth surface of the ocean can be considered a wave. This includes the ripples that may be only a twentieth of an inch high to the mountainous waves found in a hurricane which may exceed a height of 50 feet.

The driving force behind these waves is the wind. Friction between the wind and the surface of the water raises small ripples. As these ripples grow larger, the wind forms them into waves by a pressure action and by a pulling action. The pressure action is the transfer of energy from the wind to the wave, which takes place because the wind pressure on the windward side of the wave is greater than that on the leeward side. The pulling force is a transfer of energy from the air to the water caused by the difference in the velocity of the air particles and the water particles (shear stress). The pulling force is the more important of these two wind actions. As this process continues, the waves become larger and their growth exposes more surface for the wind to act on. In time the waves, or the "sea" as we'll call it when speaking of all the waves in a large area, will become *fully arisen*. That is, the waves have become as high as possible for the existing wind conditions.

Three basic factors control how high waves may get at any particular time. These are the *wind speed*, the *duration*, or length of time the wind has been blowing, and the *fetch*, which is the length of open sea over which the wind has been blowing in about the same direction.

For example, a wind of 10 knots would require a fetch of 10 nautical miles and a duration of a little less than 2 1/2 hours to develop a fully arisen sea. In this case, the *average* wave height would be about 1 foot and the *highest* waves slightly less than 2 feet.

A fetch of 800 miles and a duration of 44 hours would be required to develop a fully arisen sea with 40 knots of wind. Here the *average* wave height would be 28 feet and the *highest* waves almost 60 feet.

The storm area where waves are being developed is called the *generating area*. In this region, the sea appears chaotic and the waves are called *wind waves* or *sea*. The individual waves are shaped like mountains. They will have sharp angular tops and many small waves will be superimposed on the larger ones. At wind speeds greater than about 10 knots many white caps appear as the wind breaks the tops of the waves. Figure 1.1 is a photograph of wind waves or sea.

The crests of the waves are generally lined up at 90° to the wind and the distance between crests is short. The length of the crest is about two to three times the distance between crests (see fig. 1.2). In places the crests will appear to be lined up and regular, and in other areas the crests will be broken and confused.

1.1.1 Sine Waves

A simple wave, or sine wave as it is called, has certain fixed characteristics and is quite predictable. Figure 1.3 is an example of such a wave showing the terminology that will be used throughout this manual.

Height (H) is the height of the wave measured in feet vertically from the lowest part of the trough to the highest point of the crest.

Direction (D) is the direction from which the waves are coming.

Length (L) is the wavelength, or the horizontal distance measured in feet from crest to crest or trough to trough.

Period (P) (not shown in fig. 1.3) is the time in seconds it would take for one complete wavelength *(L)* to pass a fixed point.

Obviously, real waves are not this simple. Ocean waves can, however, be thought of as being made of many such sine waves superimposed on top of each other. Figure 1.4 shows what happens when two simple waves are added together. In the ocean there are so many different combined waves that generalizations must be made using *averages* rather than measuring and predicting the behavior of *single* simple waves.

Figure 1.1. Wind Waves or Sea.

As an example of how wave height can vary in a small area, studies of many wave records show that if the average height of the waves is 10 feet, then one third of the waves in this particular sea state will be about 16 feet high and one tenth of the waves will be 20 feet high.

1.1.2 The Movement of Water with Respect to the Wave

When you look at waves it appears that the whole surface of the sea is moving at the speed of the waves. Actually this is not the case. The water is moving up and down in a circular or elliptical path as the wave moves through the water surface; only a small amount of water during each cycle actually moves in the direction the wave is travelling. Figure 1.5 illustrates this point.

Thus, there is very little horizontal transport of the water. The wave is a vehicle for transporting energy across the surface of the ocean rather than actually transporting water.

1.1.3 Wave Movement

If a mass, such as water, wind, or even a projectile or missile, is being transported across the earth's surface it will be deflected from a straight path because of the rotation of the earth. This is known as the coriolis effect. This effect will cause any moving mass to be deflected to the right of motion in the Northern Hemisphere and to the left of motion in the Southern Hemisphere (see fig. 1.6).

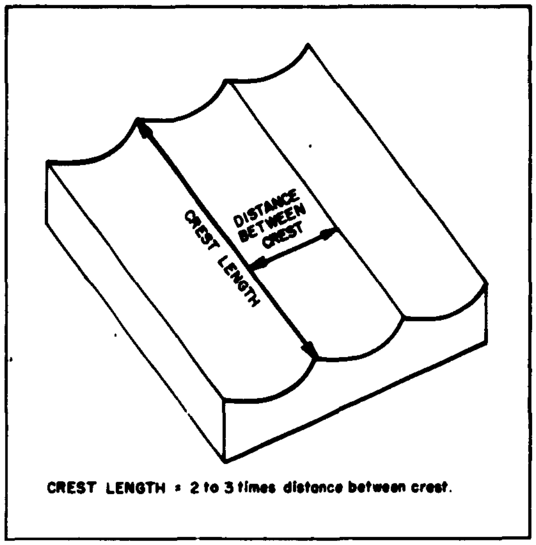

Figure 1.2. Wind Waves - Crest Length vs. Distance Between Crests.

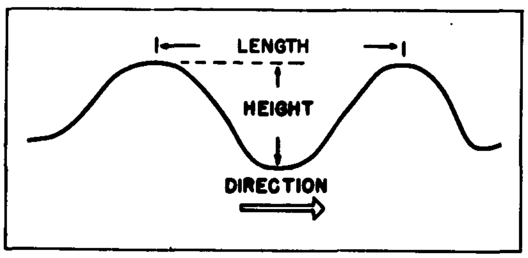

Figure 1.3. A Simple Wave.

Waves, transporting no mass, are not affected this way; thus, as the winds in a wave generating area curve because of the coriolis effect, the waves generated by the wind will continue in a straight path and will leave the storm area, losing their source of energy. Once the waves have been separated from their energy source, by either the curvature of the winds or by the dissipation of the storm, they become *swell.*

1.2 Swell

Swell, is more regular and has a longer period than wind waves. The length of the swell crests is *at least* six or seven times the distance between swells and *usually* is even considerably longer than this. With the wind no longer adding energy to the waves, the tops become rounded and much lower due to the energy lost as a result of the resistance of the water to motion and the spreading out or the dispersion of the waves. Figure 1.7 depicts a ship pounding in heavy swell.

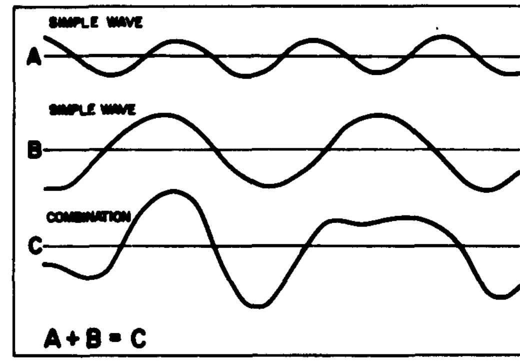

Figure 1.4. A Combination of Two Simple Waves.

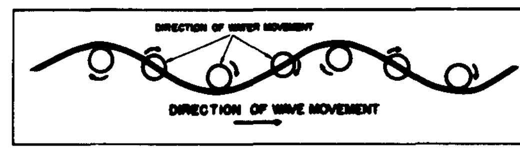

Figure 1.5. Water Movement in a Wave.

One of the biggest differences between swell and wind waves is that a swell pattern is regular, at least for a short period of time. The characteristics of any one swell can thus be predicted by observing the swells that passed before it. However, swell will not remain constant over a long period of time; at any one point distant from the generating area, the ocean waves will be caused by swell of continuously decreasing period.

Swell, if not interrupted by a land mass or a storm that regenerates the sea, will travel

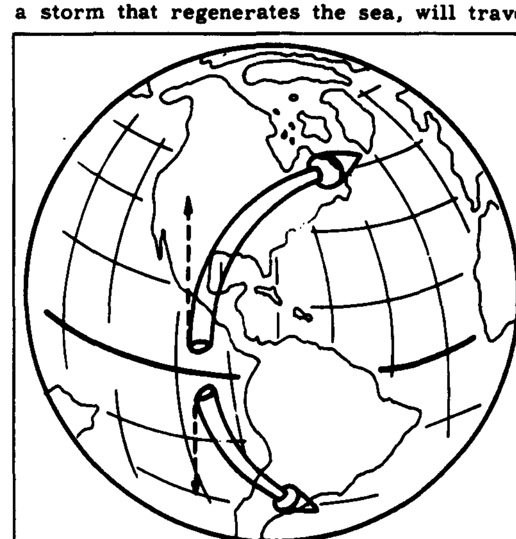

Figure 1.6. The Coriolis Effect - Showing the Direction of Deflection in the Two Hemispheres.

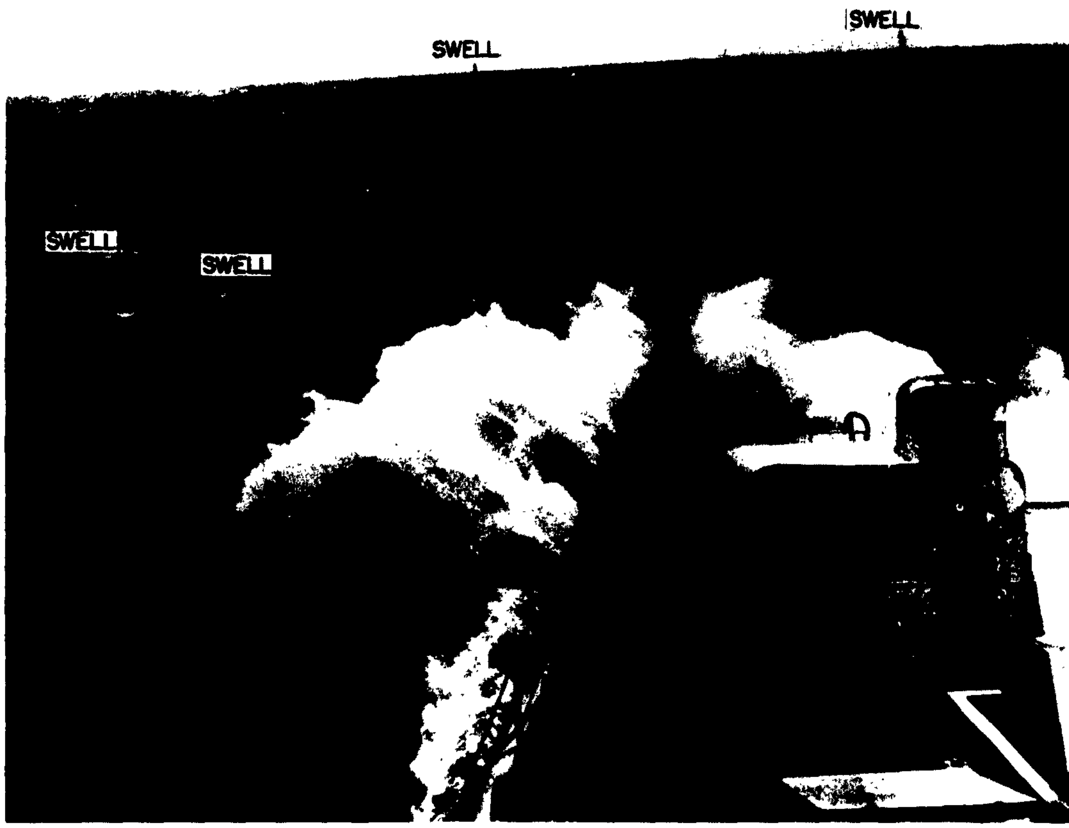

Figure 1.7. Heavy Swell.

many hundreds of miles and in some cases all the way across oceans.

1.3 Combinations of Swell and Wind Waves

Wind waves and swell, though very different in their characteristics, do not always occur separately. Quite often a storm will develop wind waves in an area that is already under the influence of the swell from another storm. The wind waves will grow on top of the swell and will give a pattern similar to that illustrated in figure 1.8. Many times the swell and the wind driven sea will be from different directions giving what is known as a *cross sea* (fig. 1.9). The same can be true of two swell systems coming from different generating areas or from a single swell system that has been refracted by an island (fig. 1.10). Although with a combination of sea and swell it is sometimes difficult to visually determine the presence of swell, the motions of the ship will usually indicate whether swell is present. Swell will be of a much longer wavelength than wind waves and the longer the wavelength of swell, the more the

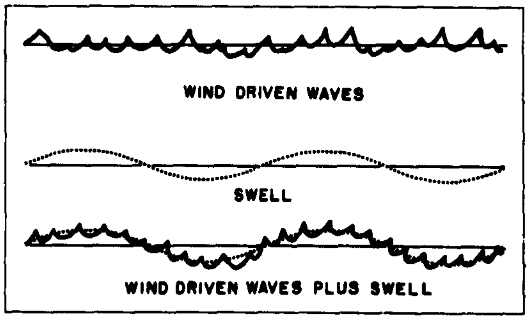

Figure 1.8. Wind Waves and Swell in Combination.

Figure 1.9. Cross Sea.

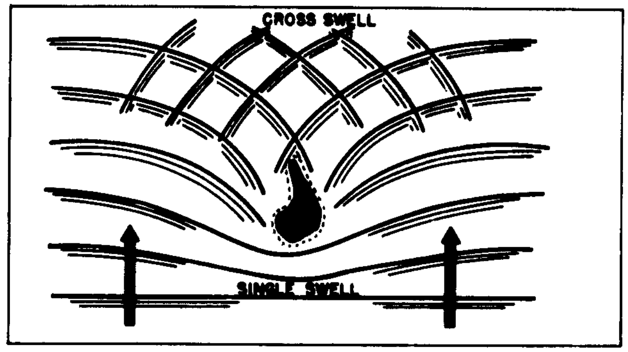

Figure 1.10. Cross Swell Produced by Swell Refraction Around an Island.

ship will pitch and roll (see fig. 1.11).

Often a moderate wind sea will be sufficient to hide a long period swell and there will be considerable roll to the ship with no apparent reason to an observer who is not familiar with ship behavior in an open ocean. It is situations such as this that require a great deal of practice on the part of the observer to determine the individual characteristics of the sea and of the swell.

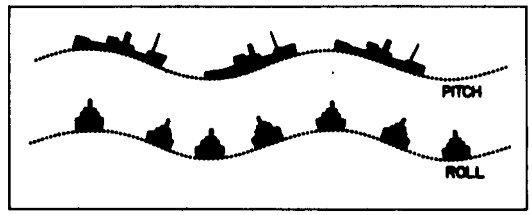

Figure 1.11. Effect of Swell on a Ship.

2. THE OBSERVING OF OCEAN WAVES

2.1 General Discussion

Wave records from a fixed point on the sea, such as from an oceanographic observation tower, show intervals of up to 5 or 10 minutes in length during which the height of the waves is quite high or low compared to the average height for the period (fig. 2.1). Thus, a quick look at the surface of the water will not be a sure measure of the sea state around the ship. To get a good observation, measurements should be carried out over a period of at least 15 minutes.

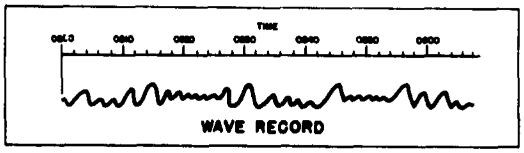

Figure 2.1. Example of a Wave Record.

The characteristics of sea state which should be normally reported on the ship's deck log (or on WBAN 11B for ships with weather units) are the *direction*, the *period*, and the *height* of either the wind waves (sea) or the swell; if both wind waves and swell are clearly present, the individual characteristics of both should be reported. Specific instructions concerning the coding and the transmission of these observations may be found by quartermasters in OPNAVINST 3140.37 - "Manual of Synoptic Weather Observations for Ship's Deck Log"; weather service personnel should use Circular N.

2.2 Measuring Wave Direction

The most accurate method of measuring the wave direction is with an alidade. This instrument consists of a gyro compass repeater over which is mounted a moveable telescopic sight. The compass repeater gives the ship's heading and the sight can thus indicate the true bearing (direction) of any object sighted upon. If the instrument is sighted parallel to the orientation of the wave crests, then the direction *from* which the waves are coming may be obtained by reading the true bearing (direction) of wave crest orientation; since wave crests are lined up at 90° to the wave direction, the observer simply needs to *add* 90° to this bearing if the waves are moving from his right to his left or *subtract* 90° if they are moving from his left to his right. If the sum of the crest bearing and 90° is greater than 360°, then 360° must be *subtracted* from this sum to yield the direction of wave travel.

Figure 2.2 depicts an observer sighting on wave crests with the alidade; in this example, the observer in determining wave direction would *add* 90° to the bearing of the wave crests because the waves are moving from his right to his left.

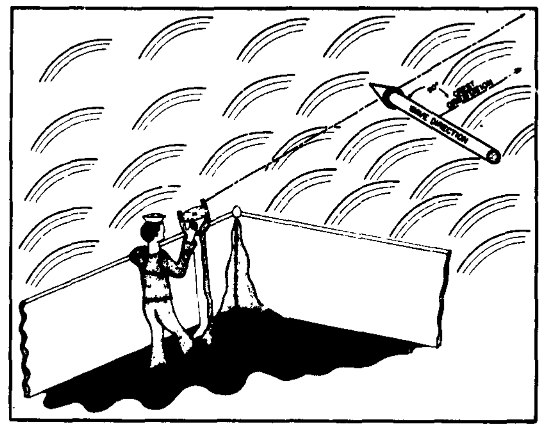

Figure 2.2. Sighting Crest Orientation with an Alidade.

Swell direction is usually less difficult to observe than wind wave direction since a line of bearing along a swell crest is usually easy to determine due to the long crest associated with swell. However, if the swell becomes hidden under a wind sea, the observing of swell direction becomes increasingly difficult and a more careful observation will be required.

The crests of wind waves will not be as regular as swell, and you will find that in order to get a good estimate of wind wave direction you will have to take an average sighting along a group of wind wave crests and use the average bearing of the group as the direction of wave travel.

Sometimes when observing wave direction you will find more than one wave system. Wind sea and swell often come from different directions, and at times there will be two or more systems of each. Under these circumstances, a careful observation must be made in order to pick out and report the *dominant* system in each case.

If an alidade is not available to measure wave crest bearing, a fairly reliable observation can be made by estimating the wave direction (not the crest orientation) *relative* to the ship from a high point on the ship. A simple diagram or the use of a maneuvering board and knowledge of the ship's course will quickly give the true direction of wave travel. The direction of wave travel relative to the ship, measured from 0° to 360° clockwise from starboard to port, added to the true course of the ship is the true direction of wave travel. Should this total be over 360°, then 360° should be subtracted from the total. In figure 2.3 the wave direction relative to the ship is 60°, the ship's course is 15°, thus the true wave direction is 75°.

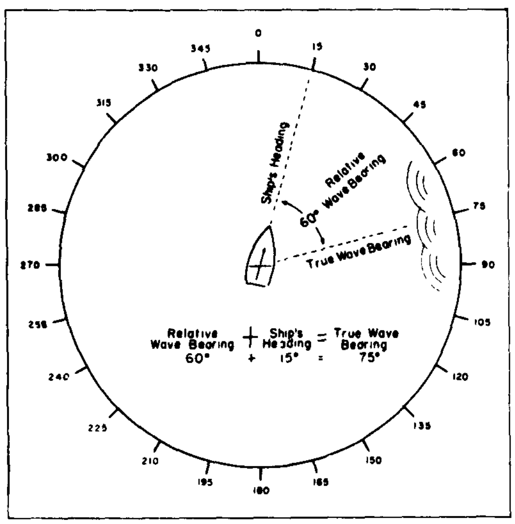

Figure 2.3. Finding the True Wave Direction.

2.3 Measuring Wave Period

As in wave direction measurements, an elevated position on the ship is preferred when estimating wave periods. Pick out an object on the surface such as a clump of seaweed, some floating debris, or even a patch of foam. Start a stop watch as the chosen object reaches the crest of a wave and stop the stop watch when it reaches the next crest.[1]

Considering the variability of periods in any one area of the sea surface, at least 50 and if possible 100 individual periods should be measured and averaged. The average value of these measurements will be a more representative value of the wave period.

Experience has shown that the preferred area to observe wave periods is 1 or 2 shiplengths ahead of the observation point on the windward side of the ship. In cases when there are no objects discernible on the sea surface, pieces of packing crate or similar material can be thrown overboard and used for reference points. A word of warning is in order here: Be sure to secure the permission of the Commanding Officer or the Officer of the Deck prior to throwing any objects overboard. You could possibly give away the ship's position when fleet exercises or combat operations are being conducted.

A method of speeding up wave period observations calls for two observers, each with a stopwatch. Observer *A* watches the reference point on the water and observer *B* logs the times. In this procedure, *A* observes the reference point at a wave crest and starts his watch. When the reference point reaches the next crest, he stops his watch and calls "start." At the call *B* starts his watch, then reads and logs the time from *A's* watch which is being held out for his view. When the time is logged *B* calls "set" and *A* resets his watch. When the reference point reaches the crest of the next wave, *A* starts his watch again and calls "stop" signalling *B* to stop his watch. Then *B* logs the time on his watch, resets it, and prepares to time the next wave on *A's* call. In this manner a large number of periods can be observed in a relatively short time. Figure 2.4 is a pictorial representation of this procedure.

Swell periods will be more regular than wind wave periods, and much longer. The main problem is usually to determine if a swell exists.

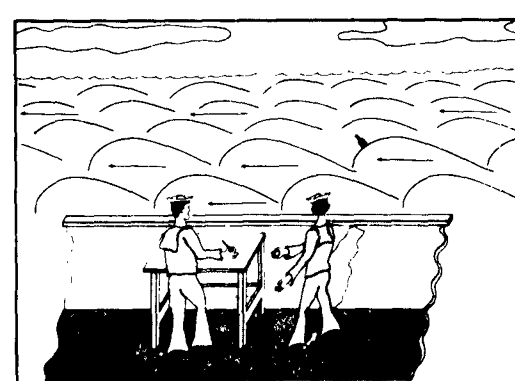

Figure 2.4. Measuring Wave Period Using Two Observers and Two Stop Watches.

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[1] *If the mark passes out of sight, a new one can be used and the process repeated until a sufficient number of values has been obtained.*

In some cases the presence of swell will be quite obvious but in others, due to either a low swell or a high wind driven sea, it will be difficult to determine the existence of swell.

A good point to remember is that, except in the heaviest seas, swell will have a greater effect on the ship's motion than a wind driven sea and its presence and characteristics can often be determined from the heave, pitch, and roll of the ship. This is mainly a matter of experience and familiarity with the individual ship. All ships will react differently to sea and swell; in fact the reactions of the same ship can change considerably under different weight and balance configurations.

2.4 Measuring Wave Height

It is possible to observe *wave height* by visually estimating the height of *all* waves seen at a point, moving with the ship's speed at a fixed bearing and distance from the moving ship. The observer should pick a point, a number of yards away and at an angle to the bow (45° for example), and estimate the vertical distance from the trough to the crest of each wave that passes this point (which will be moving along with the ship). The point should not be too close to the ship because near the ship the waves are distorted. An alidade, theodolite, or transit can be useful to help maintain the fixed point on the surface relative to the ship. In measuring the trough to crest height of the waves, care must be taken not to neglect the low waves in favor of the higher ones. Each wave is part of the make up of the sea you are measuring. *Every* height should be recorded as the waves pass the observation point.

In order to get a wave height that is truly representative of the sea state you are measuring, a minimum of 50 waves should be averaged. The accuracy will increase as the number of height measurements comes closer to 100; this number of observations has been shown to give a good representative value of the wave height in a given sea.

If the observer finds that it is very difficult to observe and actually count the lower waves that pass a fixed point with reference to a moving ship, he should then attempt to observe the height of *all* waves in *excess* of a certain fixed minimum height and then infer what the average height of all the waves (including those below the minimum height) would be. Table 2.1 has been included to help you utilize

Table 2.1. Average Height of all Waves - Given Average Height of Waves Higher than 4, 10, and 20 Feet.

Average Height of all Waves Higher Than 4, 10, 20 Feet: Higher Than 4 Ft.	Average Height of All Waves	Higher Than 10 Ft.	Average Height of All Waves	Higher Than 20 Ft.	Average Height of All Waves
4.86	2.50	12.1	6.25	33.2	25.0
5.30	3.13	12.9	7.50	35.3	28.1
6.16	3.75	13.5	8.76	38.3	31.3
6.64	5.01	14.7	10.0	42.0	34.3
7.22	5.63	15.7	11.3	42.8	38.8
7.68	6.25	16.6	12.5	47.2	40.7
8.80	7.50	18.5	15.0	48.4	43.7
9.82	8.76	21.1	17.8	54.8	50.1
11.0	10.0	22.7	20.0	63.0	56.3
12.3	11.3	25.4	22.5	66.0	62.5
-	-	27.5	25.0	-	-
-	-	30.4	28.1	-	-
-	-	33.4	31.3	-	-
-	-	36.8	34.3	-	-
-	-	39.0	38.8	-	-
-	-	43.0	40.7	-	-

this method and is used to infer what the average wave height would be.

For example if you average the heights of only the waves that are higher than 4 feet and if you find that the average is 6.16 feet, table 2.1 will tell you that the average height of all the waves is 3.75 feet. This figure would then be reported as the wave height. If the average height of all waves, higher than a certain minimum, falls between two values in the table then interpolate between values to get the desired wave height.

This table has been made up from many wave records and will give a reliable estimate of wave height. It can be used for measure-

ments of waves greater than 4 feet, 10 feet, and 20 feet. One point to remember, the table cannot correct your errors. The measurements you make in order to use the table must be accurate.

When the waves are shorter than the ship, wave heights can often be measured by a comparison with a known height such as the *draft marks* on the stem or sternpost of your ship, or in the case of a cargo ship, the Plimsoll marks on the side of the hull (fig. 2.5). The side of an adjacent ship can sometimes be used when steaming in formation (fig. 2.6).

In a heavy sea when the waves are longer than the ship a different technique for measuring wave heights must be used. Find the elevation on the ship where the tops of the waves

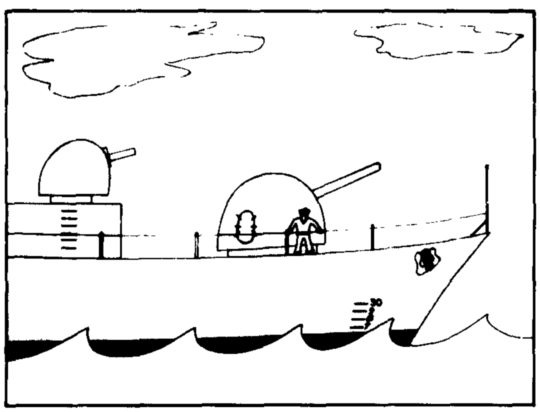

Figure 2.5. Measuring Wave Height Against One's Ship.

will appear to be level with the horizon when the ship is in a wave trough. The wave height will then be your height above the waterline (fig. 2.7). Care must be taken to make the observation at the instant when the ship is on even keel. If the ship is heeled over at the time of the observation, the height estimate will be incorrect.

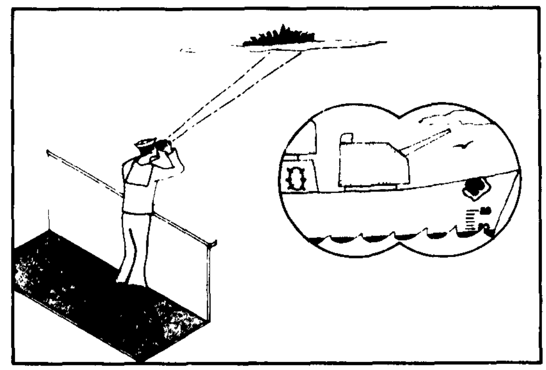

Figure 2.6. Measuring Wave Height Against Another Ship.

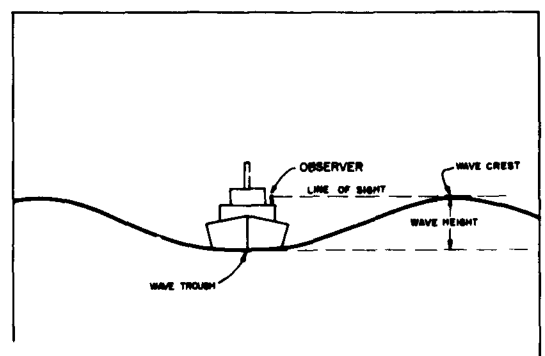

Figure 2.7. Measuring Wave Height Using an Elevated Position on the Ship.

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APPENDIX — SUMMARY OF WAVE OBSERVING METHODS

A.1 Wave Direction

A.1.1 With an Alidade

(a) Sight along the wave crests with an alidade and determine the bearing of the crests.

(b) To describe the direction that the waves (sea and swell individually) are coming from, add 90° to this bearing if the waves are moving from your right to your left (as you sight along the wave crests) or subtract 90° if the waves are moving from your left to your right. If the sum is greater than 360°, subtract 360° from the sum.

A.1.2 Without an Alidade

(a) Observe the direction the waves are coming from *relative* to the ship.

(b) Add the relative wave direction to the ship's true heading for the true direction the waves are coming from. If the sum is greater than 360°, subtract 360° for the direction.

A.2 Wave Period

A.2.1 With One Stop Watch and One Observer

(a) Using a stop watch, measure the length of time it takes for an object on the sea surface to go from one wave crest to the next. Fifty to one hundred periods should be measured and averaged. Measure sea and swell individually.

A.2.2 With Two Stop Watches and Two Observers

(a) The measurements can be speeded up by utilizing two observers and two stop watches (see page 7).

A.3 Wave Height

A.3.1 With a Relative Fixed Point

A.3.1.1 Using All Waves

(a) Pick a fixed point relative (moving with) to the ship and estimate the trough to crest height of 50 to 100 waves and average. A transit, alidade, or theodolite can help maintain a fixed point on the surface of the water.

A.3.1.2 Using Only Waves Higher than 4, 10, or 20 Feet

(a) Estimate only the heights of the waves *higher* than 4 feet, 10 feet, or 20 feet, whichever is most practical.

(b) Average and enter the table on page 8 for the average height of *all* the waves (including those below 4, 10, or 20 feet).

A.3.2 With Ship Markings

(a) Use any available markings on the side of your ship or a nearby ship if in formation, and estimate the heights of the waves passing along the side. Use an average of between 50 and 100 measurements.

A.3.3 With a Point on the Ship and the Horizon

(a) In very high seas find a point (i.e., elevation) on the ship where the crests of the waves, when sighted from your elevation, are even with the horizon when the ship is in a wave trough and on an even keel. Your height above the water line will equal the wave height.

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UNCLASSIFIED

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A brief discussion of ocean wave characteristics emphasizing the differences between wind waves and swell is first presented. Chapter 2 illustrates the procedures (one or more) which can be used to observe wave direction, period, and height.

These procedures are summed up in a concise form in the appendix.

1. Oceanography.
2. Ocean Waves.
3. Wind Waves.
4. Swell.
5. Observing.

I. Title: Observing Ocean Waves.

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